# REPORT DOCUMENTATION PAGE

AFOSR-TR-96

0348



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | | FINAL 01 SEP 93 TO 31 AUG 95 |

**4. TITLE AND SUBTITLE**

RESEARCH IN NONLINEAR SYSTEMS

**5. FUNDING NUMBERS**

F49620-93-1-0570
61102F 3484/ZS

**6. AUTHOR(S)**

PHILLIP HOLMES

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

CORNELL UNIVERISTY
DEPARTMENT OF THEORETICAL & APPLIED MECHANICS
CENTER FOR APPLIED MATHECMATICS
220 KIMBALL HALL
ITHACA, NY 14853

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

AFOSR/NM
110 DUNCAN AVE, SUITE B115
BOLLING AFB DC 20331-0001

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

F49620-93-1-0570

**11. SUPPLEMENTARY NOTES**

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

APPROVED FOR PUBLIC RELEASE:
DISTRUBUTION UNLIMITED.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** (*Maximum 200 words*)

SEE REPORT FOR ABSTRACT



**14. SUBJECT TERMS**

**15. NUMBER OF PAGES**

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | SAR |

**Second and Final Annual Technical Report on AASERT grant No AFOSR F49620-93-1-0570: ``RESEARCH IN NONLINEAR SYSTEMS''**

Period 9-1-94 to 8-31-95.

There were no charges levied on this grant during the first year 9-1-93 to 8-31-94. The monies were used in academic year 1994-5 to support two PhD students, each in the final year of study and both working jointly with the PI on this grant, Philip Holmes, as well as John L. Lumley and Gal Berkooz. (The latter was Holmes' PhD student, who graduated in 1991.) The students and their general research areas are as follows:

Brianno Coller (Theoretical and Applied Mechanics): Control of nonlinear dynamical systems with heteroclinic cycles.

The first paper on controlling heteroclinic cycles has appeared [1]. A second paper [2], the text of an invited presentation at the Twelfth U.S. Congress on Applied Mechanics, appeared in mid 1994. In it we extend the methods for control of strongly nonlinear symmetric ODEs having heteroclinic cycles, developed earlier, to higher dimensional systems which provide more realistic models of the turbulent boundary layer. In Spring 1995 we completed a more extensive paper [3] in which we describe the use of optimal control theory in designing an algorithm to delay "bursting" (transit of heteroclinic cycles) in a fairly general class of symmetric systems, which includes those appearing in low dimensional models of the turbulent boundary layer. In addition, Coller improved the analysis in [1] of passage times in the presence of controlling vector fields and white noise perturbations.

Brianno Coller has completed all degree requirements at Cornell and will be taking up a postdoctoral fellowship in the Control and Dynmaical Systems Program at CalTech.

Hal Carlson (Mechanical and Aerospace Engineering): Direct numerical simulations and analyses of flows in channels with variable geometry.

Carlson, Berkooz and Lumley, with the PI's assistance and input, completed three papers describing the development of a variable geometry code for flow in a channel with a time-dependent bump (vortex generator) in the lower wall. The first [4] deals with validation for laminar and low Reynolds number flows. The second [5] deals with the flow field modifications consequent on raising a Gaussian bump into a primarily laminar flow; bumps of various shapes are considered. The third [6] addresses the possibility of drag reduction by introducing controlled vorticity, via the bump, to cancel or modify naturally existing streamwise vortices in the near wall region. Evidence is produced showing that drag can indeed be reduced by suitable bump placement and actuation.

Hal Carlson completed his degree requirements at Cornell and graduated in May 1995. He is currently a postdoctoral fellow at Cornell.

Both projects are related to the parent grant (currently in its final no cost extension year) of this AASERT award: AFOSR NM 91-0329 "NONLINEAR DYNAMICAL SYSTEMS IN MECHANICS AND BIOLOGY" and also to the AFOSR/ONR/NSF grant F46920-92-J-0287 "STRUCTURE AND CONTROL OF THE WALL REGION IN A TURBULENT BOUNDARY LAYER."

During this period Coller was an exchange scholar at Princeton University, to which the PI moved in summer 1994. Carlson remained at Cornell, where he used the Cornell National Supercomputer Facility for his numerical work.

References.

[1] B.D. Coller, P. Holmes and J.L. Lumley, Controlling noisy heteroclinic cycles. Physica D 72, 135-160, (1994).

[2] B.D. Coller, P. Holmes and J.L. Lumley (1994) Control of bursting in boundary layer models. 12th U.S. National Congress of Applied Mechanics, Seattle, WA, June 26-July 1, 1994. In "Mechanics USA 1994" ed. A.S. Kobayashi. Appl. Mech. Rev. 47 (6), part 2, S139-S143.

[3] B.D. Coller and P. Holmes and J.L. Lumley, Suppression of bursting. Submitted to utomatica, May 1995.

[4] H.A. Carlson, G. Berkooz and J.L. Lumley, Flow in a channel with complex, time dependent wall geometries: A pseudo-spectral method. J. Comp. Physics (in press, 1995).

[5] H.A. Carlson, Flow over an emerging obstacle. Physics of Fluids (in press, 1995).

[6] H.A. Carlson and J.L. Lumley. Active control in the turbulent boundary layer of a minimal flow unit. Submitted to J. Fluid Mech, April 1995.